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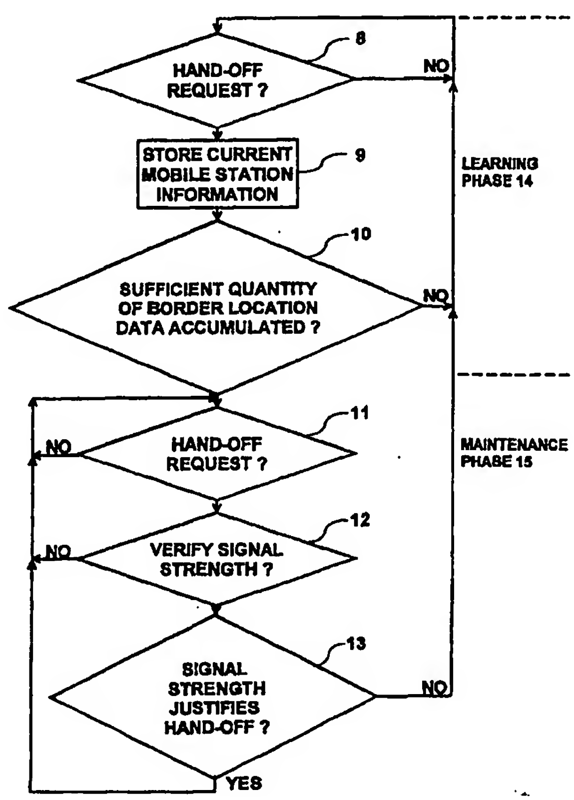
(54) Title: USE OF MOBILE STATION POSITIONING FOR HAND-OFF

(57) Abstract

A method for selecting a target cell for hand-off in a radiocommunication system uses mobile station location, direction, and speed information to determine the likelihood of the mobile station arriving at a border of the target cell. The system reserves a channel in the target cell for hand-off when the likelihood of the mobile station arriving at the target cell reaches some predetermined value.



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USE OF MOBILE STATION POSITIONING FOR HAND–OFF

BACKGROUND

Cellular communication systems conventionally consist of a plurality of base stations arranged in a pattern so as to define a plurality of overlapping cells which provide radiocommunication support in a geographic area. A remote transmitter/receiver unit communicates with the base station of the corresponding cell in which the remote unit resides. This communication typically occurs through a channel assigned to the connection by the system. When the remote unit is mobile, or when the base station is non-stationary (i.e., an orbiting satellite), the remote unit may transition between adjacent cells due to the relative movement between the remote unit and the base station. Absent some intervention by the system, this transitioning would eventually terminate the connection because the received signal strength associated with the signals would diminish to a level where either the base station or remote station cannot adequately receive the other's transmissions to decode information associated therewith. Transitioning between cells can additionally cause a significant degradation in signal quality. This signal quality degradation is typically measured at the mobile station by a quality measure such as bit error rate (BER). Signal quality degradation and termination of communication due to inadequate signal strength represent aspects of the cell transition problem in mobile cellular communications.

A solution to these aspects of the cell transition problem is commonly called "handover." This conventional technique "hands off" an in-process communication with a remote unit from one base station in a first cell to another base station in another cell. This hand-off process maintains the continuity of the connection and prevents the termination of the call when the mobile station is moving from one cell to another. The hand-off process may be accomplished using a number of system dependent methods.

In existing analog systems, for example, a serving base station determines the need for a handoff of a mobile station whose connection it is handling based on periodic measurements of the signal strength and/or signal quality of the uplink voice channel signals received from that mobile station. If the measured signal strength and/or signal quality is below a predetermined level, the serving base station sends a hand-off request to the mobile switching center. The mobile switching center queries neighboring base stations for reports of the previously measured signal strength of signals on the voice channel currently being used by the mobile station. The mobile switching center selects the target candidate cell associated with the neighboring base station reporting the strongest signal, provided that the reported signal strength is above a threshold, and transmits appropriate commands to that neighboring base station and to the mobile station via the serving base station to implement the handoff on the same or a different traffic channel.

In digital or dual-mode systems, as specified for example in the EIA/TIA IS-136 standard, hand-off from a digital traffic channel may also be implemented using a Mobile-Assisted Handoff (MAHO) procedure. Using this procedure, a mobile station may be ordered by the network to measure and report signal strength and/or other parameters of digital radio channels emitted by the serving base station, as well as those emitted by neighbor base stations. This enables handoff decisions made by the network to be based not only on the measured signal strength and other parameters of the uplink signal received from the mobile station, but also on the downlink signal parameters detected by the mobile station on channels associated with the serving and neighbor base stations.

The conventional techniques for target cell selection discussed above, where either uplink or downlink signal quality measurements are performed, suffer from a number of deficiencies when used in a hand-off process. In these conventional target cell selection techniques a signal quality decrease is necessary to trigger hand-off. Therefore, due to this signal quality decrease, call quality can be negatively affected or

the mobile station can even lose contact before hand-off is executed. Further, the time required to execute hand-off is increased because of the necessity of locating and verifying signal quality measurements for several neighboring cells before a target cell can be determined.

An additional problem with these conventional techniques is that target cell selection based solely on signal quality measurements can result in the selection of a target cell that is not necessarily the best candidate among the neighboring cells. For example, as shown in Figure 1, the mobile station 1 may be traversing an area in a direction 2 where the neighboring cells (3, 4, 5) are overlapping. If a target cell is selected solely on signal quality measurements using conventional techniques then interim cell 4 may be selected for hand-off even though cell 5 would be the better candidate to provide service for an extended period of time.

One solution to the problem of target cell selection is exemplified by U.S. Patent No. 5,551,058 (Hutcheson et al.). This patent describes a method for target cell selection in a cellular communications system, using signal quality information and mobile and base station location data, that alleviates the problem of undesirable interim target cell selection noted above. By using a method which takes into account mobile station data in addition to signal quality data, Hutcheson et al. provides a method for cell selection which minimizes the number of hand-offs and reduces the probability of hand-over failure.

In accordance with the method of Hutcheson, a mobile station acquires data that indicates its location and then analyzes the signal quality of neighboring base stations that are contained in a previously defined control list. The signal quality of each base station in the control list is compared against a threshold value and, if the threshold value is met, the mobile station stores the cell associated with that base station in a candidate cell list. The mobile station then acquires an updated location of each candidate cell in the candidate cell list. Using candidate cell location data and the mobile station location data, the mobile station calculates a range rate for each

candidate cell, i.e., the rate at which the base station is approaching or receding from the mobile station. The mobile station then compares the range rate of each of the candidate cells to determine the candidate cell with the largest calculated range rate. A determination of the difference between the range rates of each of the candidate cells and the candidate cell with maximum range rate is then made by the mobile station. Those candidate cells that exhibit a proximity to the maximum range rate within a threshold value are retained in a second candidate cell list. The mobile station then evaluates the signal quality of each of the candidate cells in the second candidate list, i.e., by making measurements associated with each of the candidate cells. From this evaluation, the mobile station selects the candidate cell with the best signal quality as the target cell.

Thus, Hutcheson refines the conventional technique of determining candidate cells using signal quality information by introducing an additional parameter that indicates the rate at which a candidate cell is approaching or receding from a mobile station. Like conventional techniques, Hutcheson does require signal quality verification for several neighboring cells before hand-off can be executed. Therefore, similar to previous target cell selection techniques, the processing involved in verifying signal quality for several neighboring cells will increase the time required by Hutcheson to execute hand-off.

In contrast to Hutcheson, U.S. Patent 5,235,633 (Dennison et al.) provides a method of target cell selection that eliminates the need for signal strength measurements of neighboring cells. Dennison describes selection of a target cell for hand-off based on mobile station location information and not signal strength measurement. In the technique of Dennison, a GPS receiver is used for determining the exact mobile station location. The mobile relays the GPS location information to the mobile switching center, which then uses this location information, in conjunction with a look-up table that specifies cell boundary points, to select the most appropriate target cell for hand-off.

Dennison appears to suggest the selection of a cell that is closest to the current location of the mobile station as the target cell for hand-off. This technique of target cell selection is deficient, however, in that it is possible that the mobile station may traverse the cell border before hand-off can be initiated depending on the mobile station speed and the duration of the intervals between receipt of the mobile station position reports. Further, according to Dennison, hand-off is initiated only when location data indicates that the mobile station is crossing the cell border. Hand-off failure may therefore occur since a free channel may not be available in the target cell at that time.

Once a target cell is selected, the conventional handoff process typically involves transferring the connection from a channel in a cell associated with a first base station to a channel in a target cell associated with a second base station. Difficulties in this handoff process can occur, however, when a free channel is not available in the target cell. Non-availability of a free channel in a target cell will block a handoff request and result in a disruption of communication service to the remote unit.

Techniques for minimizing handover disruption include reservation and non-reservation based systems. In non-reservation based systems, handover requests are prioritized based on a queuing scheme such as a first-in-first out scheme. In a system using this scheme, all queued handover requests will be served before any new calls originating in the target cell are served. In reservation based systems, a number of free channels are reserved in each cell for handover requests. The number of reserved channels typically are fixed or dynamically adjustable.

U.S. Patent No. 5,530,912 (Agrawal et al.) exemplifies a reservation based method for determining when to reserve a channel in a selected target cell for an approaching mobile station. Agrawal describes channel reservation using a pre-handover zone adjacent to a handover region which itself is adjacent to the cell borders in a current cell traversed by a mobile station. When signal strength measurements indicate that the mobile station is entering the pre-handover zone, a channel is reserved in the target cell for handoff if a free channel is available. At the time that the mobile

station leaves the pre-handover zone and enters the handover region the mobile station is handed off to the reserved channel. However, if there are no free channels available in the target cell at this time, the mobile station handover request will be queued along with the request of other mobile stations traveling within the handover region. The queued hand-off requests of the mobile stations are then ordered based on power measurements of the respective mobile stations. The mobile station that is first in the ordered queue is then allocated the next available free channel. The technique of Agrawal thus reduces occurrences of the mobile station losing contact with the current servicing base station before hand-off is executed to a neighboring base station.

The technique of Agrawal, however, is deficient in that initiation of channel reservation is dependent on a pre-handover zone that is defined by signal strength measurements. Thus, this technique could unnecessarily initiate the reservation of a traffic channel in an adjacent cell due to poor signal strength at a point, not related to the cell border, that is somewhere in the cell.

Accordingly it would be desirable to provide a technique for target cell selection and hand-off in a radiocommunication system where a decrease in signal quality is not necessary to trigger hand-off, where verification of the signal strength of several neighboring cells is not necessary to select a single target cell, where selection of an undesirable interim cell is not likely to occur, and where channel reservation for hand-off occurs sufficiently far in advance to prevent hand-off failure and is not dependent on a pre-handover region that is defined by signal strength measurements.

SUMMARY

These desirable characteristics and others are provided by the following exemplary embodiments of the invention.

According to one exemplary embodiment of the invention a method of performing a hand-off to a candidate base station to support radiocommunication services with a mobile station that is currently served by a serving base station is

provided. The method of this exemplary embodiment comprises the steps of: (a) determining a current location of the mobile station; (b) calculating a direction of the mobile station using the current location and at least one previous location of said mobile station; (c) calculating a speed of the mobile station using the current and previous locations and a time interval between said current and previous location determinations; (d) identifying said candidate base station using the direction of the mobile station and predefined network location data, wherein said predefined network location data includes cell border data; (e) estimating a parameter associated with a likelihood of the mobile station arriving at a border of a cell supported by said candidate base station using the mobile station direction, speed, and current location; and (f) selectively handing-off said mobile station based on said estimated parameter.

According to a second exemplary embodiment of the invention a method of estimating a likelihood of a mobile station arriving at a cell border associated with a candidate base station in a mobile communications network is provided. The method of this exemplary embodiment comprises the steps of determining a plurality of positions for said mobile station; identifying said candidate base station in the mobile communications network based on said plurality of determined positions; and estimating a likelihood of the mobile station arriving at said target cell, wherein said step of estimating does not include determining received signal strength of said candidate at said mobile station.

According to a third exemplary embodiment of the invention, a method of identifying a target cell to support radiocommunication services with a mobile station is provided. The method of this exemplary embodiment comprises the steps of determining successive locations of said mobile station; calculating a direction of said mobile station using said successive locations; and identifying said target cell based solely on said calculated direction.

According to a fourth exemplary embodiment of the invention, a method of reserving channels of a candidate base station to support radiocommunication services

with a mobile station that is currently served by a serving base station is provided. The method of this exemplary embodiment comprises the steps of determining successive locations of said mobile station; storing said successive locations in a processor; using said processor, operating on said stored locations to determine mobile station direction and speed; using said processor, estimating a likelihood of said mobile station arriving at a border of a cell supported by said candidate base station; and reserving a channel of said candidate base station when said estimated likelihood exceeds a predetermined threshold.

According to a fifth exemplary embodiment of the present invention a method of channel reservation in a mobile communications network is provided. The method of this exemplary embodiment comprises the steps of providing mobile station position reports at a number of reporting intervals; determining a target cell in the mobile communications network based on said successive position reports; estimating a likelihood of the mobile station arriving at said target cell, wherein said step of estimating is independent of determining transmission/reception signal quality; and calculating a time to seize a channel in said target cell when said estimated likelihood indicates arrival of the mobile station at said target cell within a given time period.

According to a sixth exemplary embodiment of the present invention a method of
reserving a channel supported by a candidate base station in a mobile communications network is provided. The method of this exemplary embodiment of the invention comprises the steps of: (a) determining a current location of a mobile station; (b) calculating a direction of the mobile station using the current location and previous locations of said mobile station; (c) calculating a speed of the mobile station using the current and previous locations and a time interval between said current and previous location determinations; (d) identifying said candidate base station using the direction of the mobile station and predefined network location data, wherein said predefined network location data includes cell border data; and (e) estimating a parameter

associated with a likelihood of the mobile station arriving at a border of a cell supported by said candidate base station using the mobile station direction, speed, and current location; and (f) calculating a time to seize a channel supported by said candidate base station when said estimated likelihood indicates arrival of the mobile station at said target cell within a given time period.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of the invention will be understood by reading the following detailed description in conjunction with the drawings in which:

FIG. 1 is a diagram of a mobile station traversing three overlapping cells;

FIG. 2 represents an exemplary implementation of an apparatus for a cellular communications system according to the present invention; and

FIG. 3 shows a graphical illustration of mobile position reporting within a cell according to an exemplary embodiment of the present invention.

FIG. 4 illustrates a flow diagram of the hand-off learning and recording method of exemplary embodiments of the invention.

DETAILED DESCRIPTION

To provide some context within which to describe the present invention consider Figure 2, which represents a block diagram of an exemplary cellular mobile radiotelephone system, including an exemplary base station 110 and mobile station 120. The base station includes a control and processing unit 130 which is connected to the MSC 140 which in turn is connected to the PSTN (not shown). General aspects of such cellular radiotelephone systems are known in the art, as described by U.S. Patent No. 5,175,867 to Wejke et al., entitled "Neighbor-Assisted Handoff in a Cellular Communication System" and U.S. Patent No. 5,745,523 entitled "Multi-mode Signal Processing," which was filed on October 27, 1992, both of which are incorporated in this application by reference.

The base station 110 handles a plurality of voice channels through a voice channel transceiver 150, which is controlled by the control and processing unit 130. Also, each base station includes a control channel transceiver 160, which may be capable of handling more than one control channel. The control channel transceiver 160 broadcasts control information over the control channel of the base station or cell to mobiles locked to that control channel. It will be understood that the transceivers 150 and 160 can be implemented as a single device, like the voice and control transceiver 170, for use with digital control channels (DCCHs) and digital traffic channels (DTCs) that share the same radio carrier frequency.

The mobile station 120 receives the information broadcast on a control channel at its voice and control channel transceiver 170. Then, the processing unit 180 evaluates the received control channel information, which includes the characteristics of cells that are candidates for the mobile station to lock on to, and determines on which cell the mobile should lock. Advantageously, the received control channel information not only includes absolute information concerning the cell with which it is associated, but also contains relative information concerning other cells proximate to the cell with which the control channel is associated, as described in U.S. Patent No. 5,353,332 to Raith et al., entitled "Method and Apparatus for Communication Control in a Radiotelephone System," which is incorporated in this application by reference.

The mobile station 120 also includes an input device 185, such as a numeric keypad, which allows a user to interact with the mobile station. A display device 190, such as an LCD screen, provides a visual display of information to the user. The mobile station also includes memory 175.

In accordance with an exemplary embodiment of the invention, shown in Figure 2, mobile station position update information is provided to a switch 140 and then to a processor 200, 210. This position update information can be calculated in any desired manner. For example, the processor can use signal strength measurements from three base stations to triangulate the mobile station's position or the position can be derived

from a GPS receiver 220 located in the mobile station receiver 120. Any other locating technique can also be used, for example those described in U.S. Patent Application Serial No. 08/839,864 entitled "Systems and Methods for Locating Remote Terminals in Radiocommunication Systems" filed on April 22, 1997, the disclosure of which is incorporated herein by reference. If GPS is used to report the mobile station location, the mobile station can transmit position update information ("mobile position report") to the base station 110 in a regular message such as, for example, a conventional IS136 RQL radio quality message which is transmitted at approximately every two seconds. If the network performs the mobile station positioning, the position data will be available at the base station and no location data will be required to be transmitted from the mobile station to the base station The received GPS position update information can then be transferred from the base station 110 to a switch 140 and then to a processor 200, 210. The processor can be the switch processor 200 of the mobile switching center 140 or, alternatively, can be an additional processor 210 external to the mobile switching center 140. Since the monitoring of every mobile in a cell regarding position, direction, and speed would use too much capacity in the switch processor, use of an external processor will advantageously permit the transfer of a significant amount of processing load from the switch processor to the external processor.

Based on the position update information, the processor records the mobile station's identity and location at each reporting interval. The processor is then used to calculate and store the current mobile direction which is derived from each location report. The processor further calculates and stores the current mobile station speed using the distance traveled between successive position reports and also calculates and stores the location of the current target cell border using the current mobile direction and a network map stored in the processor. This network map can be constructed and stored in the processor memory using conventional techniques (as will be hereinafter discussed) and includes location information for all base stations in the network relative

to one another. The network map further includes the locations of hand-off borders for incoming and outgoing hand-offs between each cell of the network and adjoining cells.

A number of conventional location techniques can be used to determine cell hand-off borders in a network. Typically, conventional techniques use a test mobile that measures signal strength while driving between two base stations (6 and 7, Figure 1). In one such technique, called handoff based on best server criteria, the handoff border has been reached, and the location can be noted, when the signal strength from the candidate base station 7 is equal to the signal strength from the serving base station 6. This border can be confirmed by doing the same test while driving in the opposite direction.

In another technique there will be a difference between incoming and outgoing handoff borders, called handoff hysteresis. Hand-off hysteresis is used to avoid oscillating hand-offs which can occur for a mobile driving at the border of two adjoining cells. In a hand-off technique based on hysteresis criteria, the outgoing hand-off border of the cell associated with a first base station is located when the signal strength from a second base station in an adjoining cell is greater than the signal strength from the first base station plus a predefined threshold value:

$$SS_2 > SS_1 + th_{val}$$

Similarly, to determine the incoming hand-off border for the first base station, signal strength is measured while driving in the opposite direction from the second base station to the first base station. The location of the incoming hand-off border is determined when the signal strength from the first base station is greater than the signal strength from the second base station plus a predefined threshold value:

$$SS_1 > SS_2 + th_{val}$$

Using either of the above conventional techniques, a network map can be manually constructed from the collected test mobile data.

In an exemplary embodiment of the invention, the conventional techniques of constructing a network map are replaced with a technique that uses mobile station position reporting at hand-off requests for mobile stations in traffic to automatically plot inter-cell hand-off borders into and out of each cell. The position update information, received at the processor 200, 210 and derived from any of the methods discussed above, can then be used to plot inter-cell hand-off borders in accordance with a hand-off learning and recording technique of exemplary embodiments of the invention. Through implementation of the exemplary hand-off learning and recording technique, a network map can be constructed and stored in the processor memory using mobile station position reporting at hand-off requests. Using this technique, the mobile station positioning data is recorded for every cell in the network at the locations where hand-offs occur into and out of each cell using conventional hand-off mechanisms. These conventional hand-off mechanisms include determination of a hand-off border using best server or hysteresis criteria.

Exemplary embodiments of the present invention use a learning phase for constructing an initial network map and a maintenance phase for updating the map to correct for changes in the radio environment. Figure 4 illustrates a flow diagram that broadly outlines the method steps in accordance with the exemplary embodiments of the present invention. During the learning phase 14 , existing hand-off mechanisms in conjunction with mobile station position information are used to construct a network map in the switch or external processor. In one exemplary embodiment, "best server" based border identification is used. In this exemplary embodiment the mobile station requests hand-off when the downlink signal strength from the neighboring base station is equal to the downlink signal strength from the current serving base station. In this technique, the processor stores 8 the mobile station location at which the hand-off request 9 is made.

In the learning phase of another exemplary embodiment "hysteresis" based cell border identification is used. In this technique the outgoing hand-off border is identified

by determining and storing 9 the mobile station location where the current base station downlink signal strength decreases to a level at which a hand-off request 8 is initiated. The incoming hand-off border is similarly identified by determining and storing 9 the mobile station location at which a hand-off request 8 is initiated into the cell from a border cell.

Using either the "best server" or "hysteresis" criteria, a compilation of border location data is constructed in the processor memory. Over a sufficient period of time, the compiled border location data will represent a complete "picture" of the ingoing and outgoing hand-off borders for every cell in the network. When a sufficient amount of border data has been accumulated 10, the cell borders of the network will be accurately known and the existing hand-off mechanisms can be discarded. The system can then rely on mobile station location information for hand-off determinations instead of signal strength measurements.

After completion of the learning phase, another exemplary embodiment of the invention implements a maintenance phase 15 for verifying the accuracy of the cell borders maintained in memory. This maintenance mode is advantageous in that hand-off borders may change as a result of changes in the radio environment and the maintenance mode will automatically detect and correct for these cell border variations. In the maintenance mode, a specified percentage of hand-offs will have their associated downlink signal qualities checked at the recorded hand-off border to verify 12 that signal quality has decreased to the point where a hand-off is required 13. If the signal quality is sufficient to maintain a call, or if the signal quality goes below a specified level such that a possible change in the radio environment is indicated, the system would initiate a learning mode 14 for the particular cell pair associated with the hand-off request until the border has been identified.

Thus, the hand-off learning and recording technique of the exemplary embodiments of the invention accumulates hand-off positioning data from numerous mobile stations over time and constructs and records a network map. Implementation of

these exemplary techniques advantageously permits the construction of a network map that details accurate cell hand-off borders and which is automatically revised to account for changes in the radio environment.

The network map, constructed using either conventional techniques or the exemplary technique described above, can be employed along with the calculated mobile direction and mobile speed to identify a candidate cell for cell re-selection and/or handoff as will now be described in more detail. A graphical illustration of an exemplary embodiment is shown in Figure 3. As illustrated, the network map 12 has been represented in processor memory in a cartesian coordinate system with the x and y axis arbitrarily affixed to one vertex of a single hexagonal cell within the network. One skilled in the art will recognize, however, that any appropriate coordinate system might be used to maintain base station and cell border locations in the processor memory. One skilled in the art will further recognize that the hexagonal cell shown in Figure 3 is an ideal representation of a cell associated with a base station. In actuality, deviations from the ideal cell borders commonly occur due to, for example, variations in the landscape. These variations therefore induce irregularities in the actual cell borders.

Figure 3 shows the course of a mobile station as the station approaches a target cell border. At each reporting period (i, $i+1$, $i+2$, etc.) a mobile position report is made to the processor noting the current coordinate location of the mobile station (Lx_i, Ly_i). At each subsequent mobile position report, the next location coordinate (for example (Lx_{i+1}, Ly_{i+1})) is stored in memory and used to calculate the current mobile station direction and the current mobile station speed s_i. The current mobile station direction is further used to identify the coordinates of the current target cell border (CBx_i, CBy_i). The current target cell and target cell border coordinates are identified by the intersection of a line, extended from the current location (Lx_i, Ly_i) in the direction of the current calculated direction α_i, with the closest known cell border maintained in the network map stored in the processor memory.

$$\alpha_i = \cos^{-1} \frac{(Lx_{i+1} - Lx_i)}{\sqrt{(Lx_{i+1} - Lx_i)^2 + (Ly_{i+1} - Ly_i)^2)}}$$

Thus, according to a first exemplary feature of the present invention the target or candidate cell associated with a particular mobile station may be identified solely on the basis of the mobile's direction, e.g., without measuring the signal strength of each neighboring base station. For example, referring again to Figure 1, application of this exemplary embodiment of the present invention to the depicted situation would result in cell 5 being identified as the target cell. Although exemplary embodiments use mobile station direction information for the selection of a target cell, without using signal strength measurements, other exemplary embodiments may use signal strength measurements for verifying the identified hand-off candidate as the preferred target cell. Additionally, other exemplary embodiments of the present invention may use the mobile's direction as an initial identifier of a target cell which can be refined using signal strength measurements.

In addition to identifying a target cell by virtue of the mobile's direction in light of the network map, other exemplary embodiments attempt to determine a likelihood that the mobile will actually enter the identified target cell. Knowledge of the mobile station's proximity to the target cell's border and its speed can be used as a proxy for this likelihood. The current speed s_i of the mobile station can be calculated, for example, by determining the distance between two successively reported locations and dividing by the duration of the reporting interval Δt:

$$s_i = \frac{\sqrt{(Lx_{i+1} - Lx_i)^2 + (Ly_{i+1} - Ly_i)^2)}}{\Delta t}$$

Based on the current mobile station location (Lx, Ly) and the current target cell border coordinates (CBx_i, CBy_i,), the time of arrival (Arr_i) of the mobile station at the target cell border can be estimated, for example, by the following:

$$Arr_i = \frac{\sqrt{(CBx_i - Lx_i)^2 + (CBy_i - Ly_i)^2}}{s_i}$$

One skilled in the art will recognize that the speed, direction, and time of arrival calculations described above could be accomplished in a number of alternative ways. Such alternatives could include, for example, averaging of the mobile station location, speed, or direction data over time.

In one exemplary embodiment, the estimated time of arrival (Arr_i) serves as a parameter that indicates, over the current reporting interval, the likelihood of the mobile station arriving at the target cell border. As is apparent, the likelihood of the mobile station arriving at the target cell border is inversely related to the calculated estimated time of arrival of the mobile station. As the estimated time of arrival increases, the likelihood of arrival at the target cell decreases. Conversely, as the estimated time of arrival decreases, the likelihood of arrival at the target cell increases. As is further apparent, the estimated time of arrival, and thus the likelihood of arrival, is a function of the mobile station speed and the consistency of the mobile station direction. As the speed of mobile increases, and the consistency of the mobile direction towards the target cell border is maintained, the estimated time of arrival will decrease. Further, as the estimated time of arrival decreases, the likelihood of the mobile station arriving at the target cell border correspondingly increases.

A request for channel reservation in the target cell is made based on the calculated likelihood of the mobile station arriving at the target cell. When the likelihood of arrival at the target cell is high enough (for example, $Arr_i <$ n number of reporting intervals) the traffic channel in the target cell can be requested. In one embodiment of the invention, the processor will calculate a time t at which it should initiate a traffic channel seizure when the estimated time of arrival is less than one reporting interval ($Arr_i < 1$).

In another exemplary embodiment of the invention, a traffic channel in the target cell can be seized at some number p of reporting intervals before the estimated time of

arrival of the mobile station. In this embodiment, the estimated time of arrival can be used to determine the likelihood of the mobile station handing-off to the target cell. Once the traffic channel is seized, the current estimated time of arrival (Arr_i) indicates the likelihood of the mobile station handing-off into the target cell. At each reporting interval, the processor will confirm that the cell is still the target cell based on direction and determine whether the time of arrival is estimated to occur before the next reporting interval, and if so, the processor will confirm that the mobile station is to hand-off into the target cell.

The technique of identifying a candidate cell based solely on the mobile station direction, as described in the exemplary embodiments above, can be further modified to account for the situation where the mobile station is traversing an area containing macro and micro cells in a hierarchical cell structure. In a hierarchical cell structure, it would be advantageous for fast moving mobiles to be kept to the macro cells, and the slower moving mobiles to be kept to the micro cells, so as to reduce the number of hand-offs required for the fast moving mobile stations. According to exemplary embodiments using this technique, the mobile station speed could be used in conjunction with the mobile station direction to select the appropriate target macro or micro cell. If the mobile station is moving fast, a macro cell would be preferentially selected based on the mobile station direction. If the mobile station is moving slowly, a micro cell would be preferentially selected, based on the mobile station direction. Use of this technique would reduce the number of hand-off requests and thereby reduce the load on the switch processor or external processor.

An additional modification to the exemplary embodiments discussed above can also advantageously account for the circumstance where there is congestion in the initially selected target cell and a traffic channel is not available for channel reservation. In this circumstance, an additional technique can be implemented which would identify a second best target cell for hand-off. This identification is achieved by determining the distances to the closest base stations that surround the current cell in which the mobile

station is located. These mobile station-to-closest neighboring base station distances can be calculated from the position of the mobile station (determined as previously described) and the known positions of the closest neighboring base stations. Additionally, the current direction of the mobile station would be calculated. The calculated mobile station-to-neighboring base station distance information would then be used in conjunction with the calculated mobile station direction to identify the best available uncongested target cell, e.g., the closest neighboring base station that the mobile station is not heading away from. This modification to the exemplary embodiments can thus prevent hand-off failure in the circumstance where no traffic channel is available in the initially selected target cell.

The exemplary embodiments described above have a number of advantages over the conventional techniques. By using mobile station position, speed, and direction as the parameters for channel reservation, and not using signal quality measurements, hand-off can be executed before the signal quality between the mobile and base station deteriorates. Further, by targeting a single cell based on mobile position data and eliminating the need for signal quality verification of several neighboring cells, the amount of processing time required before the execution of hand-off is reduced. Additionally, since channel reservation in the exemplary embodiments of the present invention is a function of an estimated time of arrival of the mobile station at the target cell, hand-off in the present invention can be prepared by channel reservation independently of any pre-handover zone defined by signal strength measurements. Use of the estimated time of arrival of the mobile station at the target cell border (where the estimated time of arrival is a function of the speed of the mobile station) thus permits channel reservation well in advance of the cell border for a mobile station that is moving at a high rate of speed.

The present invention further decreases the likelihood of an undesirable interim cell selection (described in paragraph four of the Background section) through the use of a network map in place of signal quality measurements. The network map stored in the

processor memory effectively removes the border ambiguities due to overlapping cells (shown in Figure 1) by pre-defining the locations of hand-off borders for incoming and outgoing hand-offs between each cell of the network and adjoining cells. By pre-defining the cell hand-off borders in the network map, and by making target cell determinations through the intersection of the mobile station's current heading and the pre-defined hand-off border, the present invention can select the cell in which the mobile station will likely require the longest service from the associated base station.

Although a number of embodiments are described herein for purposes of illustration, these embodiments are not meant to be limiting. Those skilled in the art will recognize modifications that can be made in the illustrated embodiments. Such modifications are meant to be covered by the spirit and scope of the appended claims.

What is Claimed is:

1. A method of performing a hand-off to a candidate base station to support radiocommunication services with a mobile station that is currently served by a serving base station comprising the steps of:

(a) determining a current location of the mobile station;

(b) calculating a direction of the mobile station using the current location and at least one previous location of said mobile station;

(c) calculating a speed of the mobile station using the current and previous locations and a time interval between said current and previous location determinations;

(d) identifying said candidate base station using the direction of the mobile station and predefined network location data, wherein said predefined network location data includes cell border data;

(e) estimating a parameter associated with a likelihood of the mobile station arriving at a border of a cell supported by said candidate base station using the mobile station direction, speed, and current location; and

(f) selectively handing-off said mobile station based on said estimated parameter.

2. The method of claim 1, wherein said step of determining a current location occurs at periodic reporting intervals.

3. The method of claim 1, wherein said parameter is a time of arrival of said mobile station at said border.

4. The method of claim 1, wherein the current location of the mobile station is derived from GPS location information.

5. The method of claim 4, wherein the current location of the mobile station is transmitted to said base station in a report message.

6. A method of estimating a likelihood of a mobile station arriving at a cell border associated with a candidate base station in a mobile communications network comprising the steps of:

determining a plurality of positions for said mobile station;

identifying said candidate base station in the mobile communications network based on said plurality of determined positions; and

estimating a likelihood of the mobile station arriving at said border of said identified candidate base station, wherein said step of estimating is independent of determining received signal strength of said candidate at said mobile station.

7. The method of claim 6, further comprising the step of:

calculating a time to seize a traffic channel supported by the candidate base station when said estimated likelihood indicates arrival of the mobile station before a next determined position of said plurality of determined positions.

8. The method of claim 6, further comprising:

seizing a traffic channel in advance of said mobile station arriving at said cell border of said candidate base station;

calculating a likelihood of the mobile station handing-off to the candidate base station.

9. A method of identifying a target cell to support radiocommunication services with a mobile station comprising:

determining successive locations of said mobile station;

calculating a direction of said mobile station using said successive locations; and

identifying said target cell based solely on said calculated direction.

10. A method of reserving channels of a candidate base station to support radiocommunication services with a mobile station that is currently served by a serving base station, said method comprising the steps of:

determining successive locations of said mobile station;

storing said successive locations in a processor;

using said processor, operating on said stored locations to determine mobile station direction and speed;

using said processor, estimating a likelihood of said mobile station arriving at a border of a cell supported by said candidate base station; and

reserving a channel of said candidate base station when said estimated likelihood exceeds a predetermined threshold.

11. A method of channel reservation in a mobile communications network comprising:

providing mobile station position reports at a number of reporting intervals;

determining a target cell in the mobile communications network based on said successive position reports;

estimating a likelihood of the mobile station arriving at said target cell, wherein said step of estimating is independent of determining transmission/reception signal quality; and

calculating a time to seize a channel in said target cell when said estimated likelihood indicates arrival of the mobile station at said target cell within a given time period.

12. The method of claim 11, wherein said given time period is less than one reporting interval.

13. The method of claim 11, wherein said given time period is less than n reporting intervals.

14. A method of reserving a channel supported by a candidate base station in a mobile communications network comprising the steps of:

(a) determining a current location of a mobile station;

(b) calculating a direction of the mobile station using the current location and previous locations of said mobile station;

(c) calculating a speed of the mobile station using the current and previous locations and a time interval between said current and previous location determinations;

(d) identifying said candidate base station using the direction of the mobile station and predefined network location data, wherein said predefined network location data includes cell border data; and

(e) estimating a parameter associated with a likelihood of the mobile station arriving at a border of a cell supported by said candidate base station using the mobile station direction, speed, and current location; and

(f) calculating a time to seize a channel supported by said candidate base station when said estimated likelihood indicates arrival of the mobile station at said target cell within a given time period.

15. The method of claim 14, wherein said step of determining a current location occurs at periodic reporting intervals.

16. The method of claim 14, wherein said parameter is a time of arrival of said mobile station at said border.

17. The method of claim 15, wherein said given time period is less than one of said periodic reporting intervals.

18. The method of claim 15, wherein said given time period is less than a number of said periodic reporting intervals.

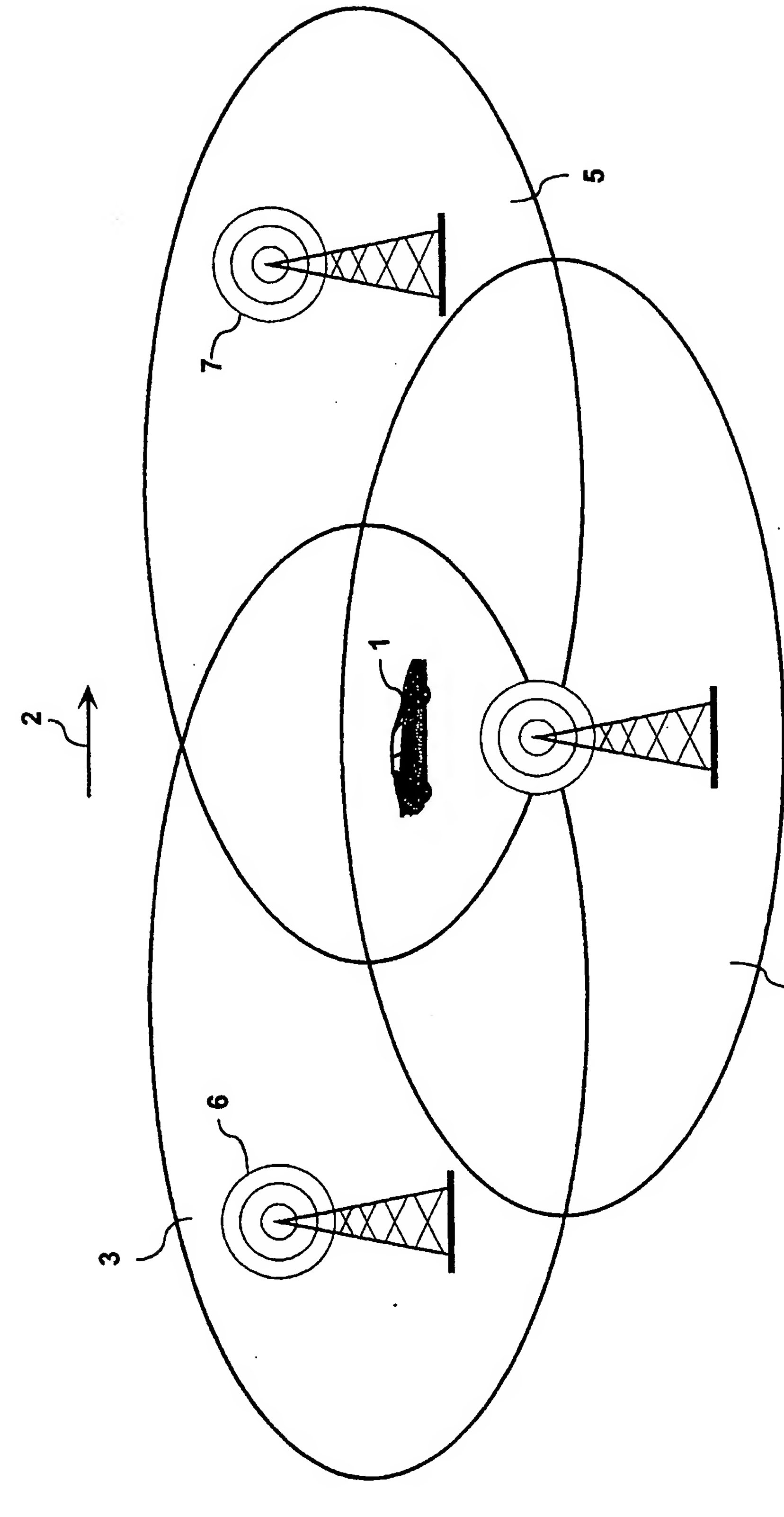


Figure 1

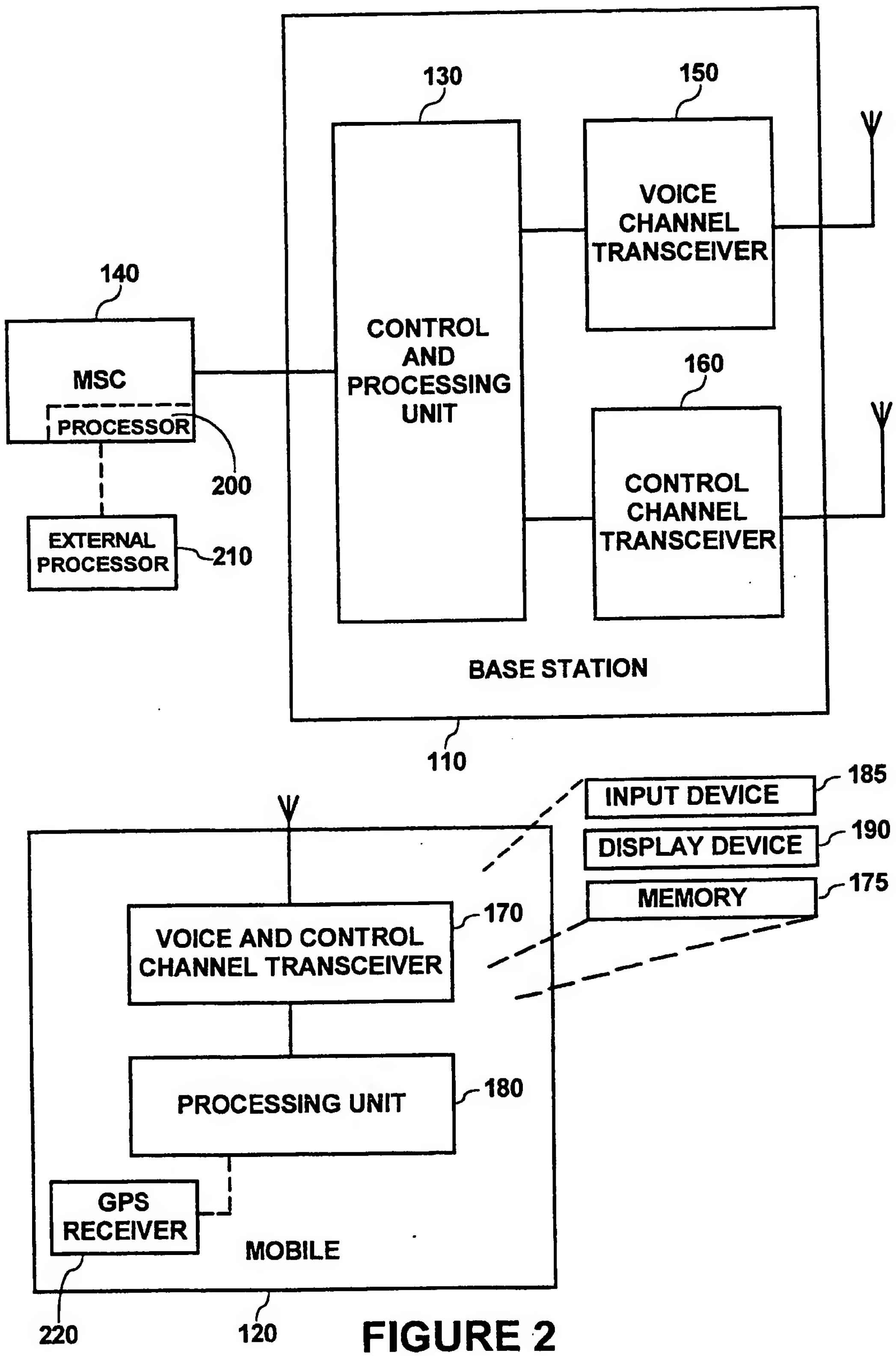

130
150
VOICE
CHANNEL
TRANSCEIVER
140
MSC
PROCESSOR
200
EXTERNAL
PROCESSOR
210
CONTROL
AND
PROCESSING
UNIT
160
CONTROL
CHANNEL
TRANSCEIVER
BASE STATION
110
INPUT DEVICE
185
DISPLAY DEVICE
190
MEMORY
175
VOICE AND CONTROL
CHANNEL TRANSCEIVER
170
PROCESSING UNIT
180
GPS
RECEIVER
MOBILE
220
120

FIGURE 2

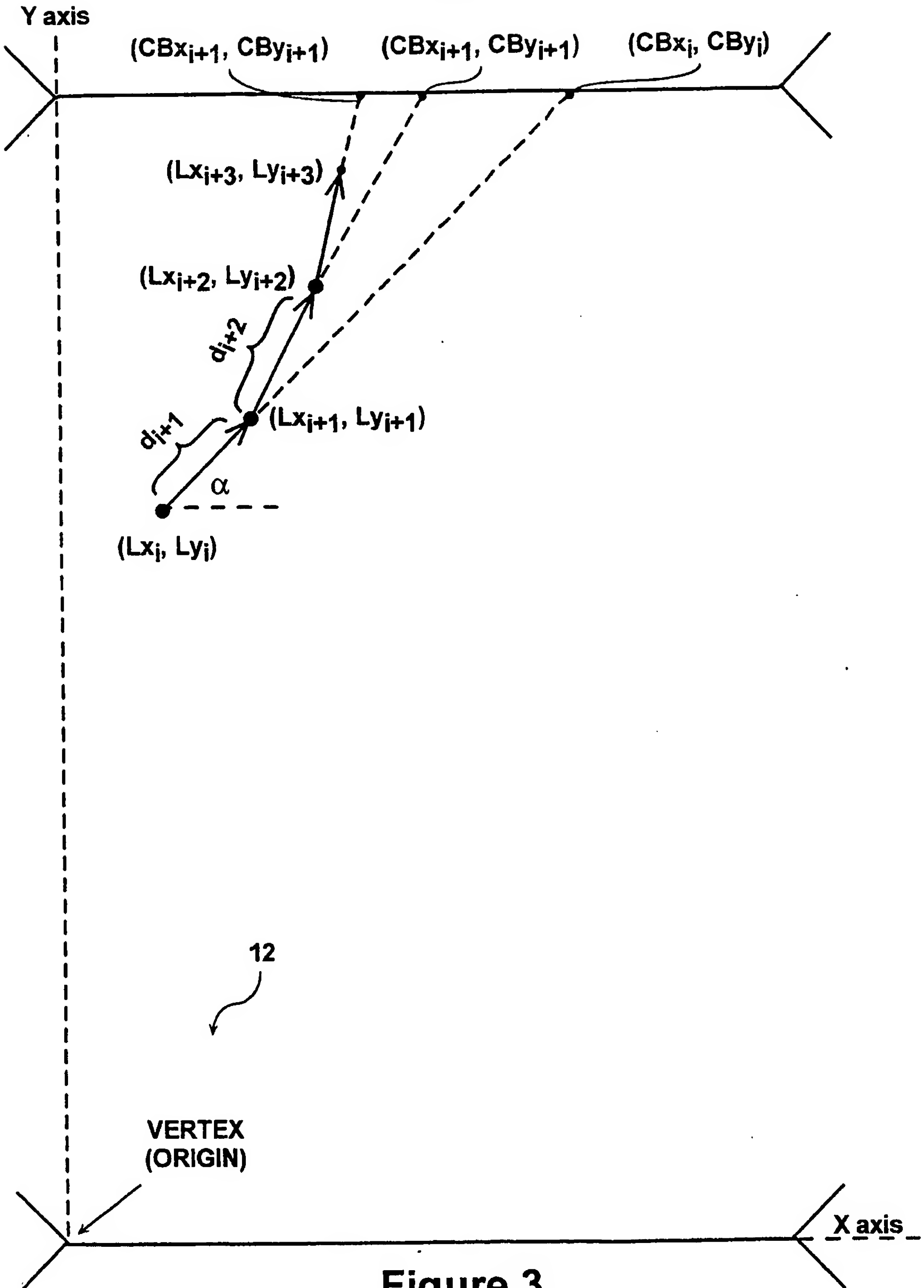
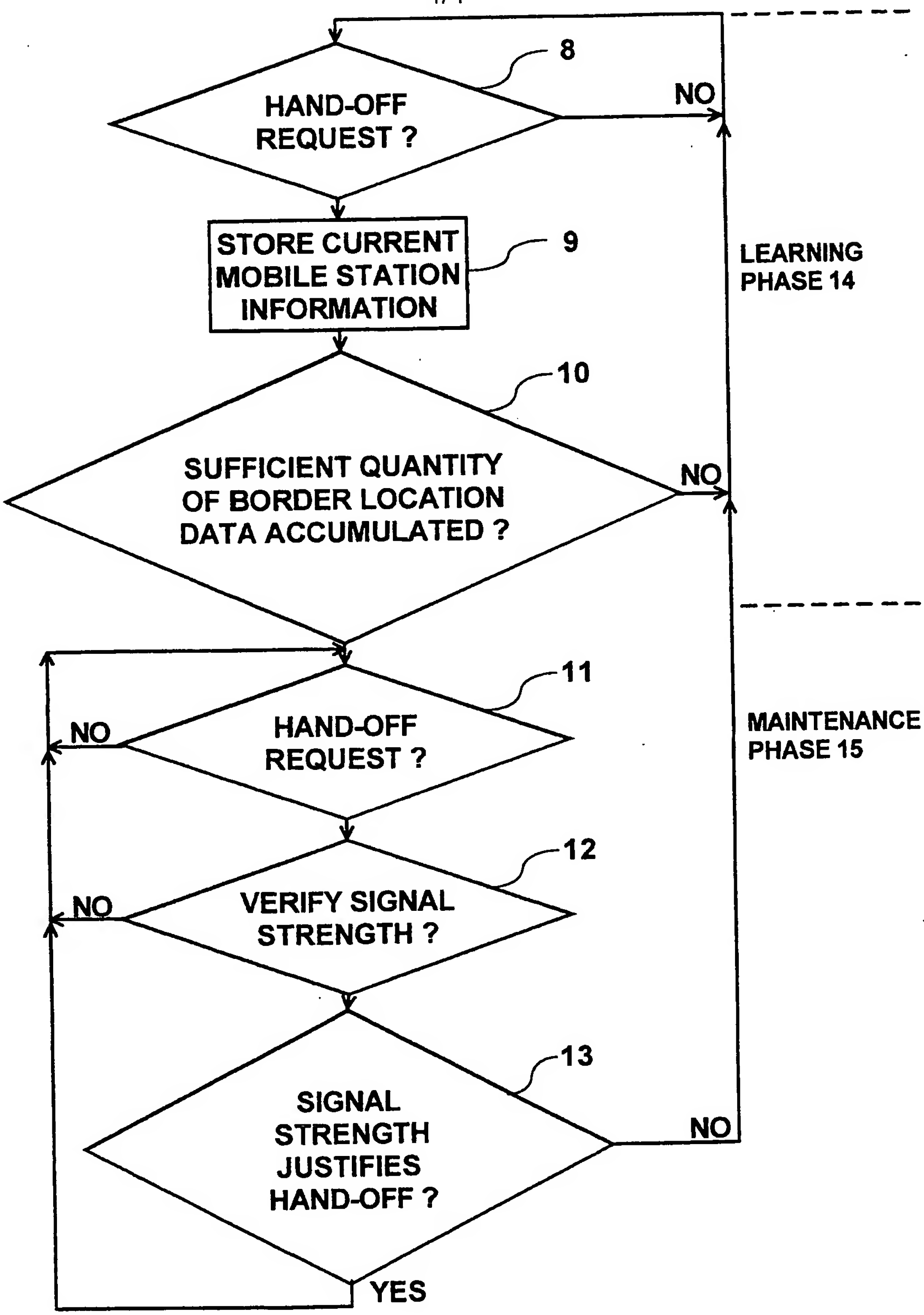

Y axis
(CBxi+1, CByi+1)
(CBxi+1, CByi+1)
(CBxi, CByi)
(Lxi+3, Lyi+3)
(Lxi+2, Lyi+2)
di+2
(Lxi+1, Lyi+1)
di+1
α
(Lxi, Lyi)
12
VERTEX
(ORIGIN)
X axis

Figure 3



8
HAND-OFF REQUEST ?
NO
9
STORE CURRENT MOBILE STATION INFORMATION
LEARNING PHASE 14
10
SUFFICIENT QUANTITY OF BORDER LOCATION DATA ACCUMULATED ?
NO
11
HAND-OFF REQUEST ?
NO
MAINTENANCE PHASE 15
12
VERIFY SIGNAL STRENGTH ?
NO
13
SIGNAL STRENGTH JUSTIFIES HAND-OFF ?
NO
YES

Figure 4

INTERNATIONAL SEARCH REPORT

Interi nal Application No
PCT/SE 99/01997

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04Q7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 432 842 A (FUJIWARA YUKINARI ET AL) 11 July 1995 (1995-07-11)	1-6
Y	column 5, line 10 -column 6, line 7	7,8, 14-18
A		9,11

X	EP 0 369 535 A (PHILIPS ELECTRONICS UK LTD ;PHILIPS NV (NL)) 23 May 1990 (1990-05-23)	10
Y	column 2, line 32 -column 7, line 49	7,8, 14-18
A		9,11

A	US 5 530 912 A (AGRAWAL PRATHIMA ET AL) 25 June 1996 (1996-06-25) cited in the application column 3, line 58 -column 5, line 25	1,6, 9-11,14

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 January 2000	24/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Kokkoraki, A

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Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/SE 99/01997

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

...ormation on patent family members

Interr   ıal Application No
PCT/SE 99/01997

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